LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

UCRL-CONF-234586

Uncertainty Detection for NIF Normal Pointing Images

A. A. S. Awwal, C. Law, S. W. Ferguson

September 13, 2007

SPIE Optics & Photonics
San Diego, CA, United States
August 26, 2007 through August 30, 2007

Uncertainty Detection for NIF Normal Pointing Images

Abdul A. S. Awwal, Clement Law and S. Walter Ferguson
Laser Science and Engineering and Operations, National Ignition Facility
University of California, Lawrence Livermore National Laboratory, Livermore, CA. 94551
E-mail: awwal1@llnl.gov

ABSTRACT

The National Ignition Facility at the Lawrence Livermore National Laboratory when completed in 2009, will deliver 192-beams aligned precisely at the center of the target chamber producing extreme energy densities and pressures. Video images of laser beams along the beam path are used by automatic alignment algorithms to determine the position of the beams for alignment purposes. However, noise and other optical effects may affect the accuracy of the calculated beam location. Realistic estimation of the uncertainty is necessary to assure that the beam is monitored within the clear optical path. When the uncertainty is above a certain threshold the automated alignment operation is suspended and control of the beam is transferred to a human operator. This work describes our effort to quantify the uncertainty of measurement of the most common alignment beam.

Key word: automated optical alignment, Gaussian beam, wavefront correction, image processing, image quality detection, position uncertainty.

1. INTRODUCTION

The National Ignition Facility (NIF), under development at the Lawrence Livermore National Laboratory, is a stadium-sized facility designed to contain a 192-beam, 1.8-megajoule, ultraviolet laser system dedicated to the study of inertial confinement fusion and the physics of matter at extreme energy densities and pressures [1]. NIF utilizes an adaptive optics system for wavefront control, which significantly improves the ability to focus the beam tightly into a millimeter size target. The 39-actuator large aperture deformable mirror is used to correct both static and dynamic aberrations [2,3]. The alignment of this high energy pulsed laser is a critical process requiring high accuracy error-free measurement [4]. If the beam alignment is not performed accurately the goal of producing high energy density and pressure can not be achieved. Moreover, optical components could be damaged by misalignment. An automatic alignment (AA) system was designed and implemented to ensure successful delivery of high energy pulse in each of the 192 beams. Currently 96 out of 192 beams are operational. The heart of the AA system is the set of algorithms which determine the position of the laser beam. The position information obtained is used to command motors to adjust the beam lines to the desired position, which facilitates the alignment of all 192 beams with a single touch operation by the control room operator.

One of the mechanisms to ensure reliability while maintaining high accuracy is to ascertain the uncertainty of the position measurement. The uncertainty expresses the position variability of an image in the presence of noise and distortions such as wavefront aberrations, diffraction noise, gradient illumination and other optical effects. The acceptable maximum uncertainty limit is set by the accuracy requirement of different loops, which may vary from half a pixel to tens of pixels. However, when the image is severely distorted say, due to mechanical malfunction such that it will be impossible to find its location reliably; reliability dictates that such images should be rejected without performing any alignment with the suspect position data. This mode of operation is known as off-normal image detection, where the off-normal image is identified and an artificially high uncertainty number is reported. The high uncertainty forces the automatic mode to be abandoned in favor of a manual mode. Only the intervention of a trained operator will allow normal execution in the automated mode. Thus both uncertainty and off-normal detection are integral part of the reliable operation of NIF laser.

There are varieties of images being processed by the algorithms throughout the beam path of each laser beam. The most common beam used for alignment is normal Gaussian beam as shown in Figure 1. In the absence of wavefront correction as shown in the second panel of Fig. 1, the beam loses its distribution symmetry thus introducing uncertainty in detecting the beam center. This work presents our efforts to determine the uncertainty of various automatic alignment images.

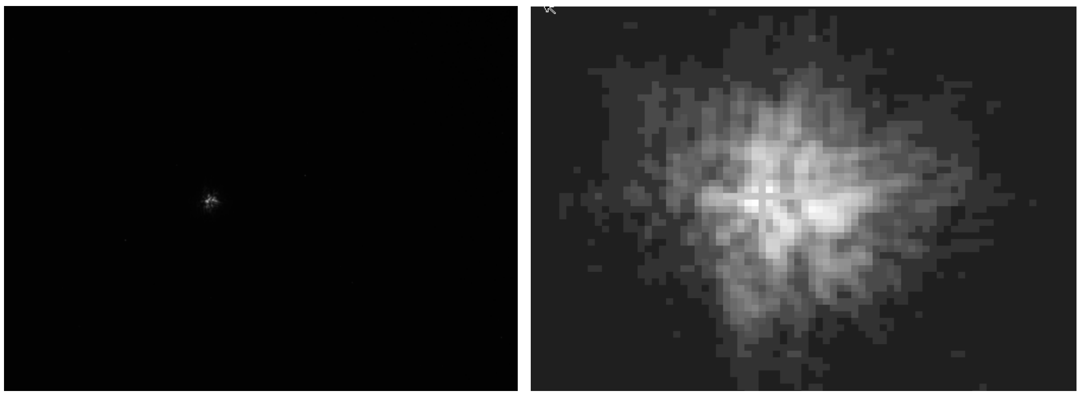

Fig. 1: The image of a typical Gaussian beam. The right side shows an expanded view of the beam.

2. COMMON ALGORITHM BLOCK

All NIF alignment images undergo a set of common algorithmic steps as depicted in Fig. 2. The first step known as off-normal processing is used to safeguard the system against accidental alignment using a false image. Thus in this step the algorithm eliminates any false, black, white or truncated images [5]. When an image is found to be normal, it is passed to algorithm, which processes the image and finds the location of the beam. At the final step, the uncertainty of the beam location is estimated [6]. The magnitude of the uncertainty depends on the quality and nature of the image. If the image is normal an uncertainty number between 0 to 2 may be generated. If the image is off-normal such as black or white image or images with outside the normal characteristics (size, intensity etc.) uncertainty of 100 or more is generated. Images that fall in between these two ranges are usually declared normal by the off-normal detector and must be processed by the uncertainty detector to assign a realistic number.

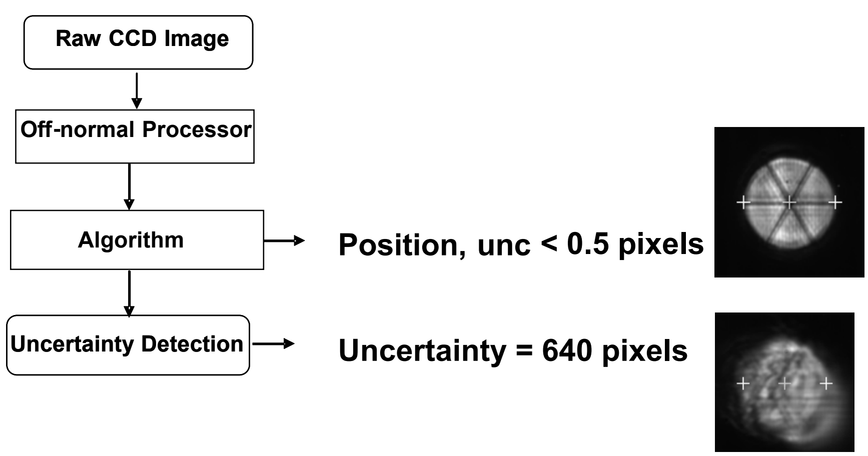

Fig. 2: The general mage processing algorithm block diagram

3. NOISE-BASED UNCERTAINTY

The source of measurement uncertainty can be traced back to noise, beam quality and the measurement algorithm. Noise in an image can add to or subtract from the signal. As a result, it will affect the position calculation such as in a centroid or in a matched filter based technique. The beam quality simply could mean part of the beam is missing or distorted by a gradient background. The measurement algorithm makes a number of assumptions regarding the background noise, beam location, uniformity of the background etc. The algorithm may choose a parameter (say, threshold) which when varied could impact the result. Thus this choice of parameter is another source of uncertainty.

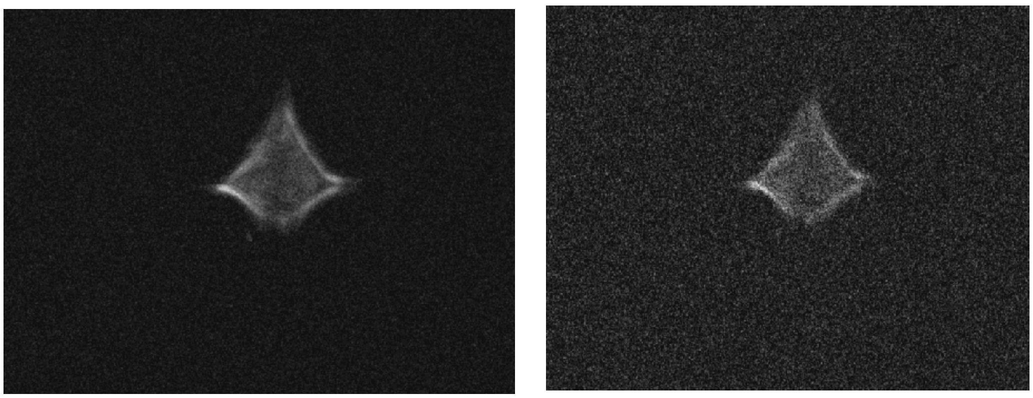

Fig. 3: 100 image sets are created for each noise and amplitude level (a) amplitude 200 and noise 20 (b) amplitude 200 noise 50 .

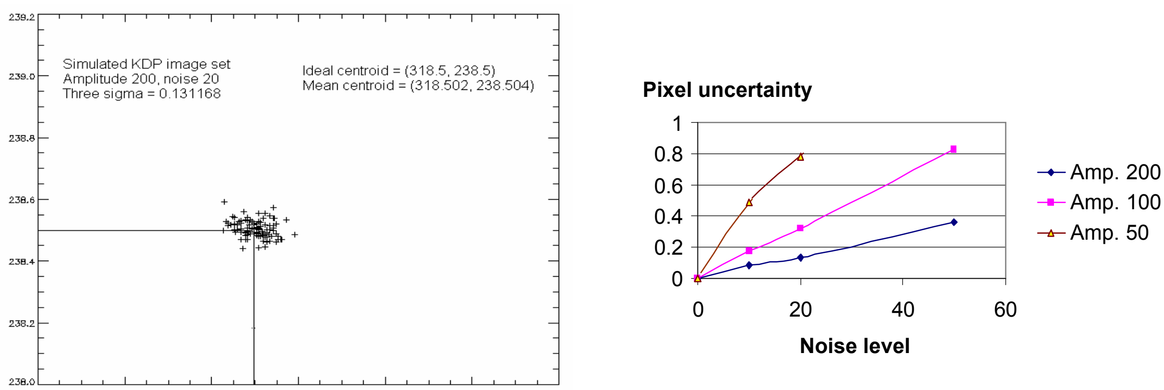

Fig. 4: The variation of the position estimate is treated as the measure of uncertainty. (b) the noise-uncertainty curve serves as a truth table for uncertainty determination.

To quantify the position variations due to noise, a Monte Carlo simulation was devised. Starting with a noise-free image, varying image intensities and noise counts are created by superimposing noise. In particular, simulated images with maximum amplitudes of 50, 100, and 200 and white Gaussian noise with an rms magnitude of 10, 20, and 50 is added to create an ensemble of 900 images. As an illustration, we show two such images with amplitude 200 and noise 20 and 50 in Fig. 3. It should be noted that the position of this particular image is obtained using a matched filter [7]. Taking sets of 100 images for each signal and noise combination, the algorithm calculates the position of the spots (displayed in Fig. 4 left panel). The three-sigma (three times the standard deviation) of the spot positions is taken as the measure of uncertainty. The uncertainty values for all nine combinations of noise and signal levels are used to plot the uncertainty curves as shown in the right panel of Fig. 4. These curves are stored as a look up table; by estimating the noise and signal from a real image, the exact value of the uncertainty is calculated by interpolation from these tables.

After noise, the second source of position uncertainty is image quality. The image quality effects will be captured when we use the algorithm to evaluate the uncertainty caused by parameter variation. In the extreme case, when quality is deteriorated significantly, the off-normal detector will trigger and indicate as such. Next we describe how we use the variations in algorithm parameter to quantify uncertainty.

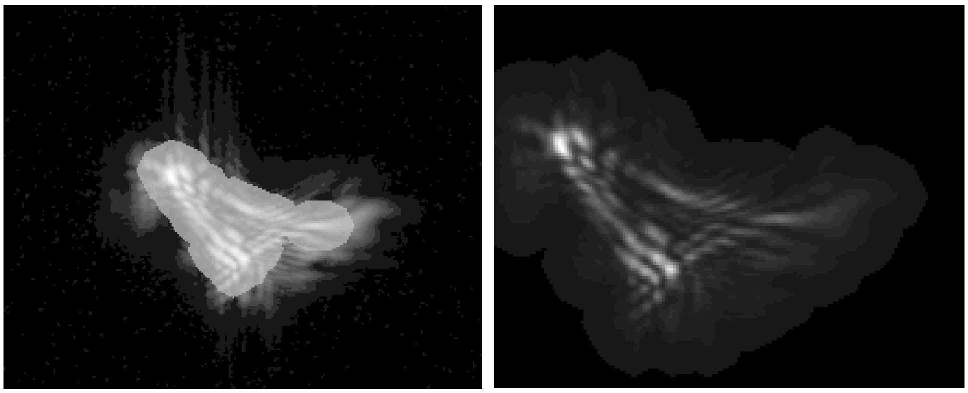

Figure 5. Expanding or shrinking the region of interest changes the centroid by 4 pixels.

4. UNCERTAINTY INTRODUCED BY PARAMETER VARIATION

One of the most common beam images encountered during NIF laser alignment is a beam with Gaussian intensity profile. A weighted centroiding technique is generally used to determine the position of such beams. In this method, a threshold representing the background noise is estimated. Then the threshold is applied to isolate the beam from the background. A weighted centroid of the segmented signal provides the position of the beam. A typical beam is shown in Fig. 5, with the region of interest (ROI) superimposed on the image for a specific threshold. As the threshold is lowered the region of interest is expanded. The centroid of the left panel is calculated as (383.688,208.505), while the right panel places the beam position at (387.107,207.555). The difference of these two results is approximately 4 pixels. For a typical symmetric beam as shown in Fig. 6, as the threshold is gradually increased from 10% to 90% of the maximum value, the right panel depicts variation of the position estimate. It is interesting to note that they are all bounded by a maximum of 0.5 pixels.

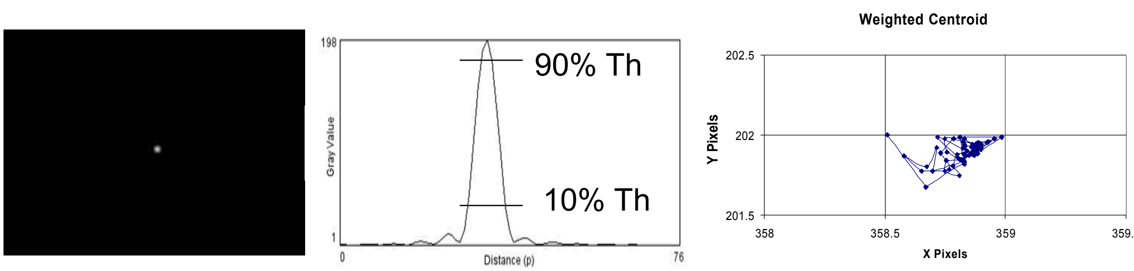

Figure 6. A normal Gaussian beam, its cross-section and position estimates as threshold changes

For our estimate of uncertainty we vary the threshold from a minimum value representing the nominal background (usually a count of 3) to half of the maximum intensity of the beam. The range of variation is expressed as the uncertainty. Accordingly the uncertainty of the beam position in Fig. 6 is less than 0.5 pixels.

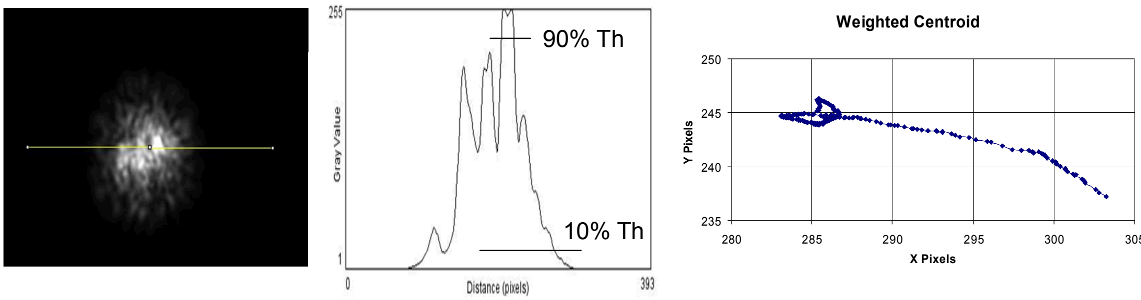

Figure 7. A normal Gaussian beam, its cross-section and position estimates as threshold changes

Fig. 7 depicts a Gaussian beam with wavefront compensation turned off. In this example, the positions vary more than 15 pixels, resulting in high uncertainty. In terms of magnitude of uncertainty, the noise based uncertainty calculated for a set of over 2500 images show that most uncertainty values are less than 0.1, whereas the proposed parameter variation based uncertainty produces numbers in the range of 0.2 to 0.4 pixels as shown in Fig. 8.

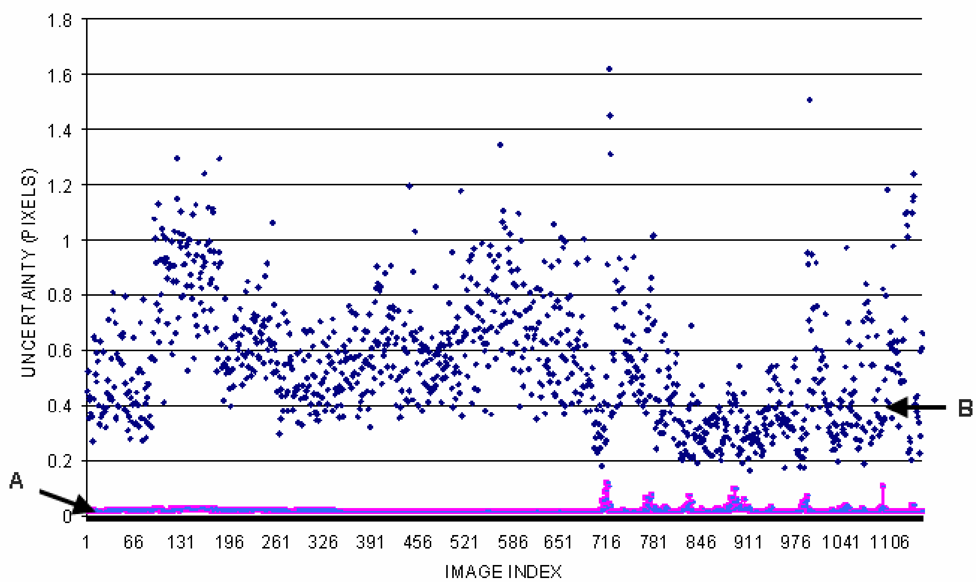

Figure 8. Comparison of the new uncertainty (B) magnitude with those of with Monte Carlo (A) based algorithm

6. CONCLUSIONS

In this paper, uncertainty detection and its use in the reliable operation of NIF laser beams are discussed. The noise based uncertainty is generally bounded by a small magnitude. The proposed parameter variation based technique usually provides a more realistic estimate of uncertainty that seems to be better correlated with image quality. Although the proposed technique is more realistic it does entail extra processing time, for example, the processing time increase from less than a second to couple of seconds. One of the challenges of the uncertainty detector is that as new sources of uncertainty arise, they must be included into the total uncertainty calculation [8]. The uncertainty estimation technique described here were applied to centroid based position detection, however, they could easily extend to other position detection schemes.

ACKNOWLEDGEMENT

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore Laboratory under contract No. W-7405-Eng-48.

REFERENCES

1. George H. Miller, Edward I. Moses, and Craig R. Wuest, "The National Ignition Facility", *Optical Engineering,* Vol. 43, pp. 2841-2853, 2004.
2. M. M. Spaeth, K. R. Manes, C. C. Widmayer, W. H. Williams, P. K. Whitman, M. A. Henesian, I. F. Stowers, J. Honig, "National Ignition Facility wavefront requirements and optical architecture," *Optical Engineering,* Vol. 43, pp. 2854-2865, 2004.
3. R. A. Zacharias, N. R. Beer, E. S. Bliss, S. C. Burkhart, S. J. Cohen, S. B. Sutton, R. L. Van Atta, S. E. Winters, J. T. Salmon, M. R. Latta, C. J. Stolz, D. C. Pigg, T. J. Arnold, "Alignment and wavefront control systems of the National Ignition Facility," *Optical Engineering,* Vol. 43, pp. 2873-2884, 2004.
4. J. V. Candy, W. A. McClay, A. A. S. Awwal, and S. W. Ferguson, "Optimal position estimation for the automatic alignment of a high-energy laser," Journal of Optical Society of America A, Vol. 22, pp. 1348-1356, 2005.
5. J.V. Candy, A. A. S. Awwal, W. McClay, S. C. Burkhart, "Detection of off-normal images for NIF automatic alignment," in *Photonic Devices and Algorithms for Computing VII*, edited by K. Iftekharuddin and A. A. S. Awwal,, Proc. of SPIE Vol. 5907, pp. 59070B-1 - 59070B-12, 2005.
6. W. A. McClay III, A. A. S. Awwal, H. E. Jones, K. C. Wilhelmsen, W. Ferguson, M. McGee, M. G. Miller, "Evaluation of laser-based alignment algorithms under additive random and diffraction noise," in *Photonic Devices and Algorithms for Computing VI*, edited by K. Iftekharuddin and A. A. S. Awwal,, Proc. of SPIE 5556 (SPIE Bellingham, WA, 2004), pp. 243-248.
7. A. A. S. Awwal, Wilbert A. McClay, Walter S. Ferguson, James V. Candy, Thad Salmon, and Paul Wegner, "Detection and Tracking of the Back-Reflection of KDP Images in the presence or absence of a Phase mask," Applied Optics, Vol. 45, pp. 3038-3048, May 2006.
8. A. A. S. Awwal, C. Law, J.V. Candy, W. McClay, W. Ferguson, and S. C. Burkhart, "Commissioning of the off-normal processor for NIF alignment images under varying imaging conditions," in *Proceedings of the Sixth Tri-laboratory Engineering Conference*, p. 16, Monterey, CA, September 12-15, 2005.